PLANETARY DEFENSE

Department of Defense Cost for the Detection, Exploration, and Rendezvous Mission of Near-Earth Objects

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EARTH IS ON a collision course! Micrometeorites regularly streak into the atmosphere causing little more than a fiery flash. However, larger near-Earth objects (NEO) can have a more dramatic effect on the Earth. Recently scientists presented evidence in which an asteroid, at least a mile in diameter, hit the ocean 35 million years ago southeast of what is now Washington, D.C., shaping the Chesapeake Bay.[1] Today such an impact would cause devastation on a global scale. The mitigation of such a natural disaster necessitates an international planetary defense. This article provides a background of the threat of NEO-Earth impacts and addresses planetary defense taskings and Department of Defense (DOD) costs for the next 20 years as part of an international effort to detect and learn more about NEOs.

Background

A NEO is a natural object (asteroid, short- or long-period comet, or a meteor stream) of any size that will come close to or cross Earth's orbit, or even impact the Earth. In the past 15 years, research on NEOs has dramatically increased as astronomers and geologists realize the Earth is nothing more than a billiard ball in a cosmic pool game. Our world was struck in the past and will be struck in the future.

Craters on Earth do not last long due to weather and geological erosion. Geologists have, however, pinpointed some very old craters. A NEO slammed into Quebec 214 million years ago, leaving a 100-kilometer-wide scar known as the Manicouagan Crater (fig. 1). In central Australia 70 million years later, another NEO created a 22-kilometer-diameter crater (fig. 2). Evidence suggests the demise of the dinosaurs occurred 65 million years ago with the impact of an asteroid 10 kilometers in diameter. Named the K/T event, the asteroid struck with the force of 100 million megatons of TNT, creating a crater 180 kilometers wide off the coast of the Yucatan Peninsula in Mexico. Even North America was visited by a NEO nearly 50,000 years ago, creating Arizona's Meteor Crater (fig. 3).[2]

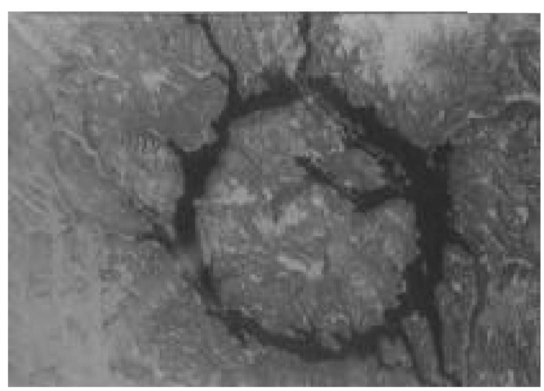

Figure 1. Manicouagan Crater, Quebec

Fig ure 2. Wolf Creek Cra ter, Aus tra lia

Figure 3. Meteor Crater in Arizona (Reprinted with permission of University of Arizona Press from Tom Gehrels, ed., *Hazards Due to Comets and Asteroids* [Tucson: University of Arizona Press, 1994], 430.)

Today there are 140 known impact sites on the Earth with many hundreds awaiting verification.[3] Figure 4 illustrates the major sites.

Earth, however, is not the only planet tormented by orbital debris. In July 1994, Jupiter was struck by Comet Shoemaker-Levy 9. The comet passed too close to the gas giant, breaking apart due to the immense gravity and then scarring the planet in several locations shown in figure 5. If even one of the kilometer-wide fragments had hit the Earth, the result would have been catastrophic,[4] as shown by the computer model in figure 6.

Meteor streams occur when the Earth passes through the orbital path of debris left behind by comets. The debris can range in size from a centimeter to a millimeter in diameter. Though these streams pose no threat to humans on the surface, satellites and space stations may be impacted, degrading their solar arrays or damaging optical sensors.[5]

Some NEOs nearly reach the Earth's surface. From 1975 to 1992, nuclear detonation detecting satellites recorded 136 atmospheric

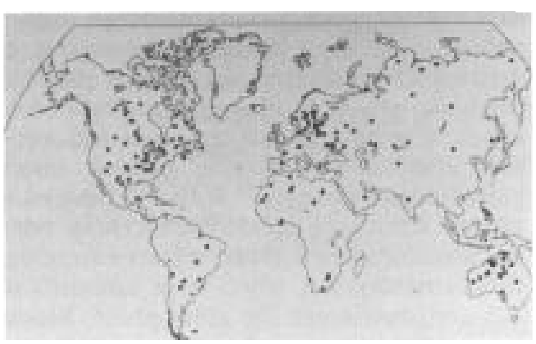

Figure 4. 140 Earth Impact Sites (Reprinted with permission of University of Arizona Press from Tom Gehrels, ed., *Hazards Due to Comets and Asteroids* [Tucson: University of Arizona Press, 1994], 430.)

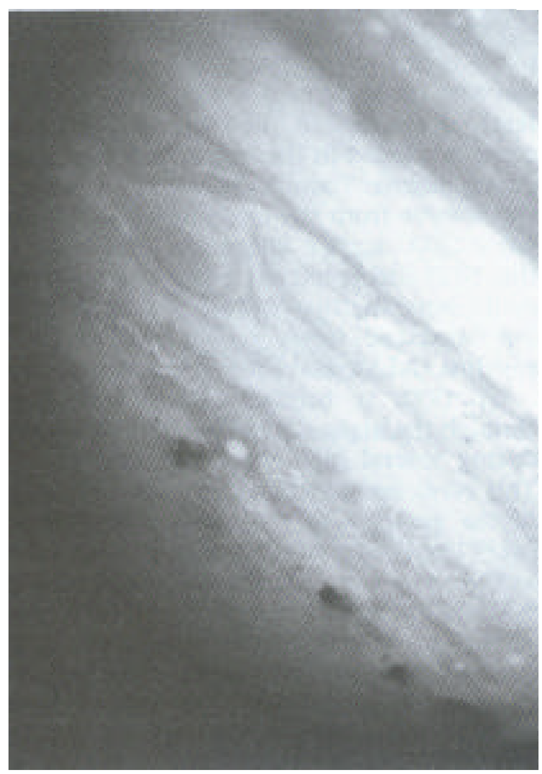

Figure 5. Impact Scars on Jupiter

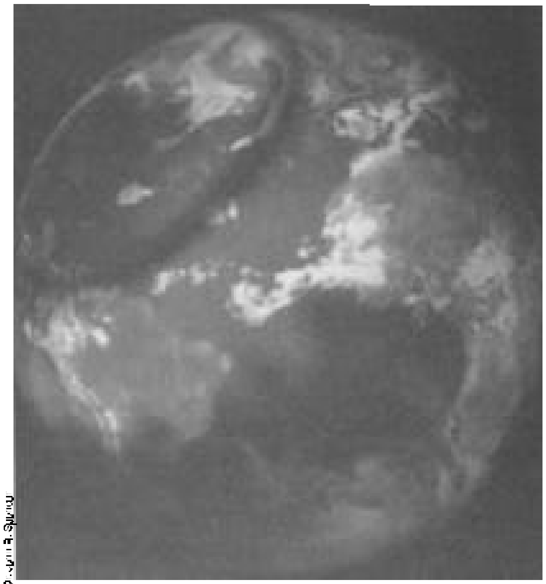

Figure 6. Simulation of Shoemaker-Levy 9's projected impact on Earth

blasts in the megatons-of-TNT range.[6] NEOs can also cause damage to the Earth without reaching the surface.[7] In 1908, an asteroid or comet exploded in the atmosphere near Tunguska, Siberia. Though no crater formed, the shock wave from the exploding body devastated 2,000 square kilometers of forest.[8] If this NEO had reentered a few hours later, it could have destroyed Moscow with a force one thousand times greater than the Hiroshima and Nagasaki atomic detonations.[9]

In 1992, a brilliant asteroid streaked through the night sky in Peekskill, New York, during several high school football games. This event was caught on a camcorder at one of the games, and the asteroid damaged a car.[10] The Tunguska blast area is twice as big as New York City and three times as large as Washington, D.C.

Luckily, not all NEO "near hits" cause damage, but they do illustrate the fact the Earth is not immune to their destructive effects. Recorded on a videocamera in 1972, an asteroid grazed Earth's atmosphere near Wyoming's Grand Teton Mountains and skipped back out into space (fig. 7).

In 1989, astronomers discovered an asteroid labeled 1989FC after its closest approach to Earth. This illustrates a disturbing fact. Currently only astronomers on shoestring, academic budgets are trying to locate and track NEOs, making estimates of NEO populations very imprecise. Through the end of 1992, 163 NEOs had been detected and catalogued, representing only 5 percent of the estimated 2,000 to 5,000 NEOs larger than one kilometer.[11] Scientists believe a Tunguska event will occur every century and a kiloton (K/T) event every 25–26 million years based on the density of impact craters on the moon.[12]

Illustrated in figure 8 is the equivalent yield in megatons of TNT based on a NEO with a density of 3 grams/centimeters (CM^3) and a velocity of 20 kilometers per second (km/sec). The shaded area to the left represents the NEO size that will burn up or explode in the atmosphere, though blast effects like Tunguska still could produce damage to the surface. Near the one-kilometer size, NEOs could produce global consequences, though there is some uncertainty in the threshold size required as shown in the dashed vertical lines.

Global disasters will result if a large (1-km) NEO impacts the Earth, perhaps killing as much as 25 percent of the human population.[13] This is largely due to the indirect effect of the impact. A land impact produces fires and earthquakes, while an ocean impact produces tsunamis measuring several hundred meters in height, and perhaps even hypercanes, which are runaway hurricanes that inject large amounts of sea water and aerosols into the atmosphere, causing major global climate changes.[14] Both will have blast effects flattening nearby structures with the possibility of a global winter emerging. Global winters are when large amounts of ash and dust enter the atmosphere, blocking sunlight from reaching photosynthesizing plants. Crops will die and world starvation may result. Also, worldwide temperatures would plummet for months, perhaps years.[15]

Figure 7. An as ter oid skips through the at mos phere, only one of many "near hits" re corded.

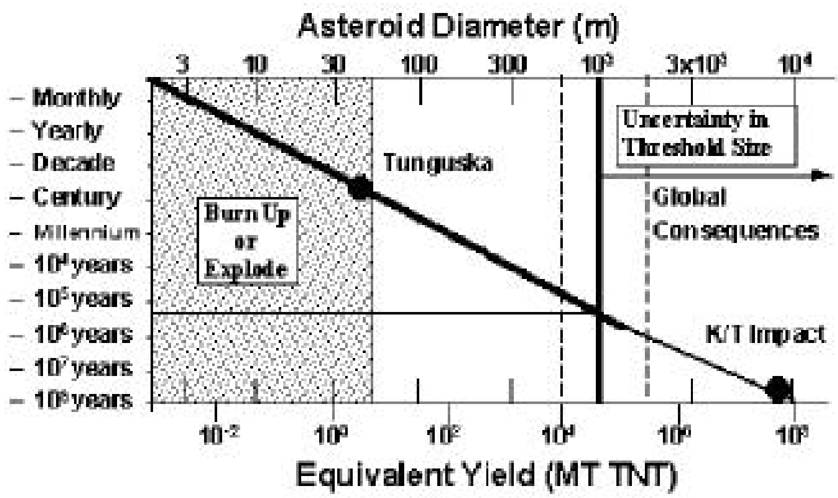

Figure 8. Average Impact Interval Versus Size (Reprinted with permission of *Nature Magazine* from Clark R. Chapman and David C. Morrison, "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard," *Nature* 367 [6 January 1994]: 37.)

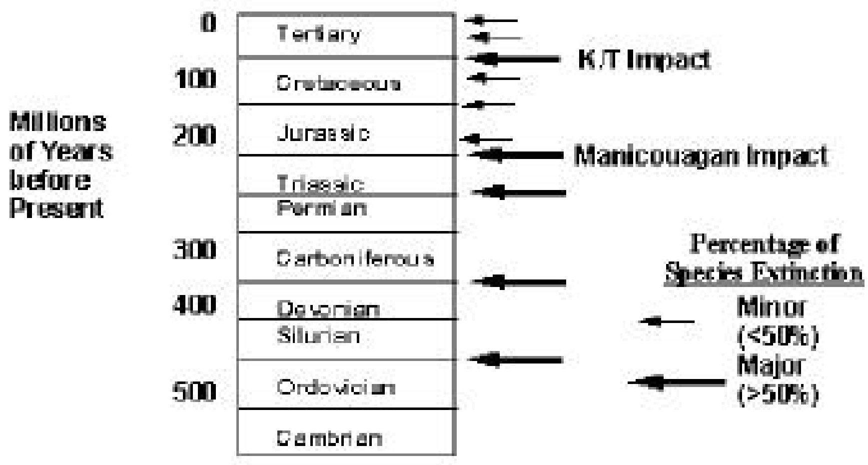

Figure 9. Mass Extinctions in Geological Record (Reprinted with permission of Plenum Press from C.R. Chapman and David C. Morrison, *Cosmic Catastrophes* [New York: Plenum Press, 1989])

Scientists have compared mass extinctions with major impact craters found on Earth and discovered a striking comparison as seen in figure 9.[16] The K/T event could have begun the demise of the dinosaur era. The Manicouagan Crater in Quebec may have also helped to end the Triassic Era by throwing tons of sky-darkening dust into the air.[17]

If a NEO impacted the Earth today, what would the estimates of fatalities be? Should we even be concerned? Figure 10 portrays projected fatalities per event. The dash line represents an ocean impact while the solid line portrays a land impact.

In figure 10, we see the curved line representing increased fatalities with increased NEO size, yet the time scale on the left indicates longer times between larger NEO asteroid diameters. In other words, small NEOs near 50 meters in diameter impact the Earth much more frequently than larger ones. However, small NEOs could produce another Tunguska blast. Therefore, one needs to understand the probability of death by any size NEO. The relative probability of death by an asteroid impact is shown in table 1.

How does one arrive at a number of 1 in 25,000? Scientists estimate there are 500,000 years per global devastating impact, as shown by the horizontal line in figure 10. The probability of a strike in any one year is 1 in 500,000 assuming the strikes are completely at random. Assuming 25 percent of the world's population could die as a result, the risk of death is 1 in 4. Thus, in any one year per person, the risk of death is approximately 1 in 2,000,000. Over a 75-year lifetime, the risk is nearly one in 25,000.[18] Please realize that the probability of a NEO impacting the Earth and causing global disasters is very slim, yet the consequences if one did impact would leave us with this estimated risk of death. Furthermore, you are probably wondering when the last person was killed by a NEO. Referring back to the Tunguska blast, the expedition that researched the blast found trees, reindeer, teepees, and nomadic artifacts partly incinerated.[19] It is still unknown if anyone did die.

By now you are thinking we're predicting that the sky is falling. We are not trying to scare the reader into spending billions of dollars to save the Earth. Rather, we ask for money to be spent wisely on assessing the threat, learning more about NEOs, and

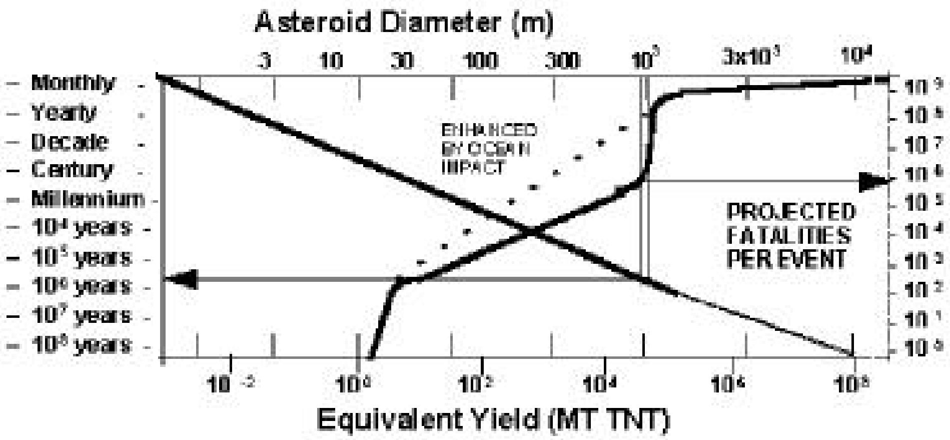

Figure 10. Estimated Fatalities Per Event (Reprinted with permission of *Nature Magazine* from Chapman and Morrison, "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard," *Nature* 367 [6 January 1994]: 37).

tracking and cataloguing NEOs. No NEO is currently predicted to hit the Earth. Yet someday there will be one, as the probability is finite. So who will take a leading role?

The US government, through the DOD, is obligated to protect the lives and safety of its citizens.[20] Further, the US may use its armed forces, under the hierarchy of interests, for cases of strict humanitarian concern.[21] Thus, responding to the NEO threat could be seen to fall under this policy.

In the past few years, several different organizations in addition to DOD began to assess the NEO threat. Astronomers working at

Table 1
Probability of Death by an Asteroid

Chances of Dying from Selected Causes in the United States

Motor Vehicle Accident	1 in 100
Murder	1 in 300
Fire	1 in 800
Firearms Accident	1 in 2,500
Electrocution	1 in 5,000
Passenger Aircraft Accident	1 in 20,000
ASTEROID IMPACT	**1 in 25,000**
Flood	1 in 30,000
Tornado	1 in 60,000
Venomous Bite or Sting	1 in 100,000
Fireworks Accident	1 in 1 million
Food poisoning	1 in 3 million
Drinking Water with EPA limit of TCE	1 in 10 million

Courtesy Dr. C. R. Chapman & Dr. D. C. Morrison

Source: "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard," *Nature* 367 (6 January 1994): 39

colleges have discovered NEOs by several methods, such as by using telescopes equipped with cameras to photograph small sections of the sky at two different times nearly an hour apart. The astronomers then compare the two photos to observe if any smudge or streaks occurred, thus representing a NEO passing by the Earth. However, it is very tedious and time consuming to peer at photographs with a microscope looking for such movement. Furthermore, if a streak does appear, the astronomers must first check to see if the streak is not a satellite flying overhead or a known asteroid or comet. Another method is to use charge-coupled devices (CCD) detector telescopes.[22] This method utilizes computers to analyze electronic photographs for any streaks that occur that are not previously known, such as satellites or NEOs that have not already been detected. The CCD method is much quicker, though more expensive. Altogether, this is only a limited search due to the astronomers' restricted academic budgets.

In 1990, the American Institute of Aeronautics and Astronautics (AIAA) issued a position paper concerning the threat of NEOs after Apollo asteroid 1989FC made the closest approach to the Earth ever detected.[23] Stimulated by this AIAA paper, Congress recognized the impact hazard of NEOs and in 1991 asked the National Aeronautics and Space Administration (NASA) to convene a detection and interception workshop. The Subcommittee on Space of the Committee on Science, Space, and Technology, US House of Representatives, received the summaries and held hearings on the threat of large Earth-orbit-crossing asteroids on 24 March 1993.[24] Ironically, Shoemaker-Levy 9 was discovered about this time. Due to the impending impact on Jupiter, Congress directed NASA to develop a program and a budget estimate for cataloging NEOs in 10 years.[25] NASA's report encourages collaboration of the international community and the US Air Force.[26] However, Congress only asked NASA to give a cost estimate, and currently NASA has no plans to spend new money on tracking NEOs.[27]

The military has also written about the NEO threat. Air University's Spacecast 2020 reported on the Air Force's future and looked at the NEO threat in "Preparing for Planetary Defense."[28] Research was conducted at Air Command and Staff College on the same topic.[29] The chief of staff of the Air Force tasked Air Force Space Command to accomplish a mission area assessment for defense of Planet Earth, which should be finished in fiscal year 1997.[30] Thus, to date there has been some attention given to the NEO threat. However, the authors believe in order to accurately assess the threat, we need to follow several taskings as elaborated in the next section.

Taskings

A planetary defense should include everything that could mitigate a NEO-Earth collision. What does one need to know or do before one can mitigate the damaging effects of a NEO collision with the Earth? Should any of these tasks be accomplished concurrently? The following list of tasks answers the previous two questions.

Coordination is required to systematically cover the sky. Several astronomers from around the world are surveying the sky, although not in a joint effort. Who will do confirmations and follow-up orbit determination? Can we use the Air Force's tracking systems to help detect NEOs?

Detection is required. What should be the limiting NEO size detected? How fast should this occur, within 10 or 20 years? The requirement for timely completion of detection affects the decision concerning sky coverage versus limiting NEO size and magnitude. What are the sources of NEOs? Should we detect possible NEOs, ones that are currently not near Earth's orbit but that might become ones? Furthermore, how often should we recheck previously scanned areas?

Science covers the material characterization of the object. What does one need to

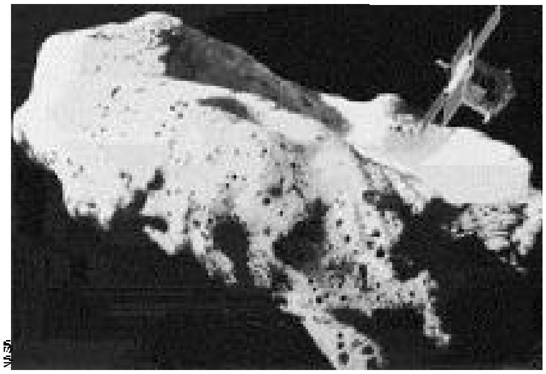

Fig ure 11. Ex plo ra tion of a NEO in the Fu ture

know about the object in order to mitigate any damage effects? Can one simulate NEO composition on Earth and "test" these NEOs? Can we deflect the orbital paths of NEOs or is destroying NEOs and suffering the remnants impacting the Earth the only option?

Exploration of NEOs may be a means to combine the requirement to rendezvous with a NEO for scientific study while providing the orbital dynamics know-how for destruction or deflection. Missions to NEOs will prove helpful in planetary defense.

Destruction and Deflection may be the only ways to prevent damage to the Earth. Operation concepts and options should be planned and practiced before they are required to be used to avoid a catastrophe.

Harvesting is a spin-off of deflection. Would Earth be lucky if an NEO was approaching? Could a NEO be "captured" into Earth orbit and then mined to provide resources in space?

Warning of the "Big One" is only good if the outcome (global devastation) is avoidable. Warning of "small" NEOs may save countless lives and prevent destruction due to tsunamis, forest fires, and earthquakes. Also, warning to prepare for a meteor stream may save valuable space assets.

Cost

Currently planetary defense is not itemized in the DOD budget. As with any organization, priorities set the budget. The apprehension from those not in DOD may be that any planetary defense could be just another excuse for an arms race since the cold war is over. The reality from the congressional perspective is that the money for any efforts specifically itemized for planetary defense should come out of DOD's current budget.[31]

Given that the funding is from DOD, support should be given to those academic research programs that are currently conducting NEO detection, research, and technology development and to the Air Force Space Command, which has spent over $100 million on the technology to improve the current space surveillance mission of the ground based electrical-optical deep space system (GEODSS). Space Command's relentless efforts of quality and continuous improvement should be lauded. Not only is there an improvement in the accuracy of detecting man-made debris in Earth orbit, but also the enhanced tracking of NEOs for a planetary defense is now feasible. Clearly, the humanitarian search for NEOs would be a hallmark for efforts to transform military assets into civilian endeavors. Furthermore, current improvements in the GEODSS can be utilized to improve environment, weather, and remote sensing, as well as to create smaller, faster, more intelligent hardware. However, tracking NEOs is not the only solution for protection. We need to learn more about NEOs and be prepared to avoid a future collision.

Over the next 20 years, NEO detection, exploration, and rendezvous missions need to take place. In a recent Air Command and Staff College study, Larry D. Bell and others provided an excellent in-depth look at search systems, their advantages and disadvantages, a system architecture, and cost.[32]

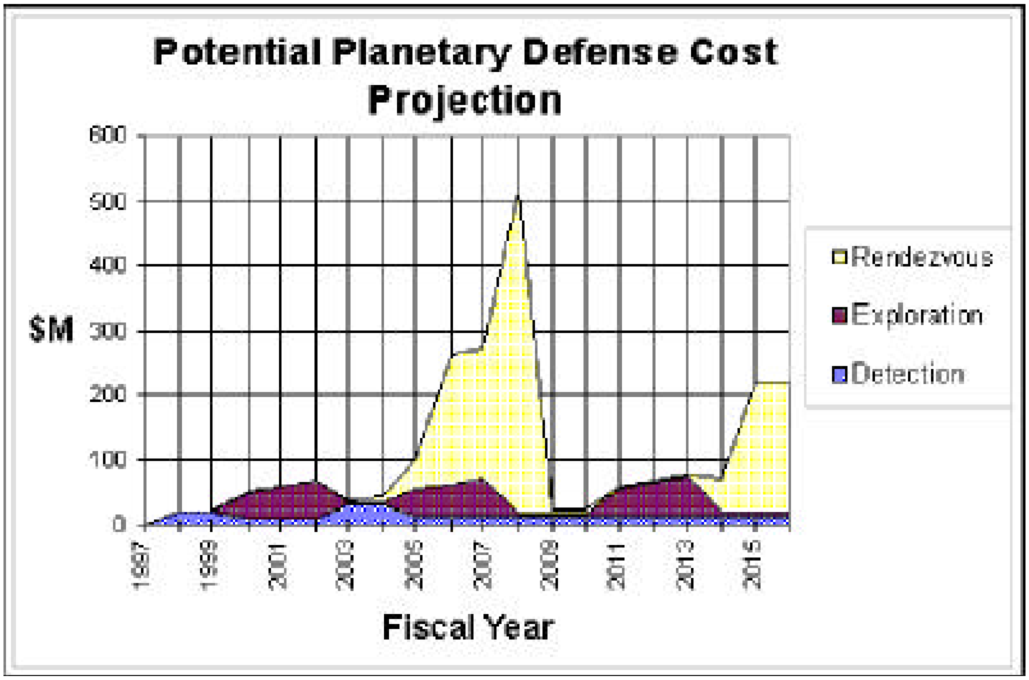

Figure 12. Projected Cost for a Potential Planetary Defense Effort

Detection includes searching for NEOs, maintaining a NEO catalog, estimating populations of NEOs, and recurring operations and support. Exploration consists of determining the NEO origins, understanding how their orbits change due to the planets or collisions, and resolving the composition and density of NEOs. Are they solid or rubble objects orbiting together? Flybys or ground-based research will be the vanguards. Missions like Galileo, Clementine 1 and 2, NASA's near-Earth asteroid rendezvous (NEAR) system, and use of the Arecibo and Goldstone radar systems will increase our knowledge of NEOs. Finally, rendezvous missions practice the meeting of NEOs beyond the Earth's orbit, testing methods to deflect or destroy an NEO. These are the practice, small-scale mitigation missions in case we need to perturb or destroy a NEO months or even years before an Earth collision occurs. The science missions may require observations from Earth or flybys of the target, whereas rendezvous missions require the interceptor to orbit the target NEO. The bottom line is that the estimated cost for a planetary defense is near $14 million per year for detection, $23 million per year for exploration, and $75 million per year for rendezvous missions averaged over the next 20 years. Figure 12 reflects the breakdown of the budget each year if we begin today. These estimated costs were finalized with comments from Mr Nick Fuhrman, science advisor to the Committee on Science, US House of Representatives, and Dr. Bill Tedeschi of the Sandia National Laboratory.

A limited mitigation system that would cost approximately $1 billion over three years is not included above.[33] A different estimate sets costs at $120 to $150 million per year for two mitigation missions to either destroy or deflect non-Earth impacting NEOs over a 10-year period.[34] The United States will perhaps need an impact scare to push Congress to approve a mitigation program because any system with the capability to deflect or destroy NEOs might be viewed as a weapon.

The cost of the detection mission also includes the installation of an infrared sensor in the year 2003 to supplement the optical system. The exploration costs are portrayed as three distinct missions launched during the years 2002, 2007, and 2013. These missions could be easily slipped forward or backward depending on what is detected and what NEO is of interest. The rendezvous missions of 2008 and 2017 should be used to develop the operations concepts and procedures for a mitigation mission.

Summary

Assessing the NEO threat would be a small cost for insurance, whereas an impact would cost billions of lives and trillions of dollars. While there is no reason to fear NEOs daily, there is a finite probability another NEO will collide with the Earth.

We have the technology to track and predict NEO-Earth impacts and the possibility of preventing a catastrophic natural disaster. Other species are extinct because they could not protect themselves. We must not be the next. Therefore, it is imperative that we use our knowledge and technology to assess the NEO threat by addressing the seven tasks and invest in the detection, exploration and rendezvous missions. □

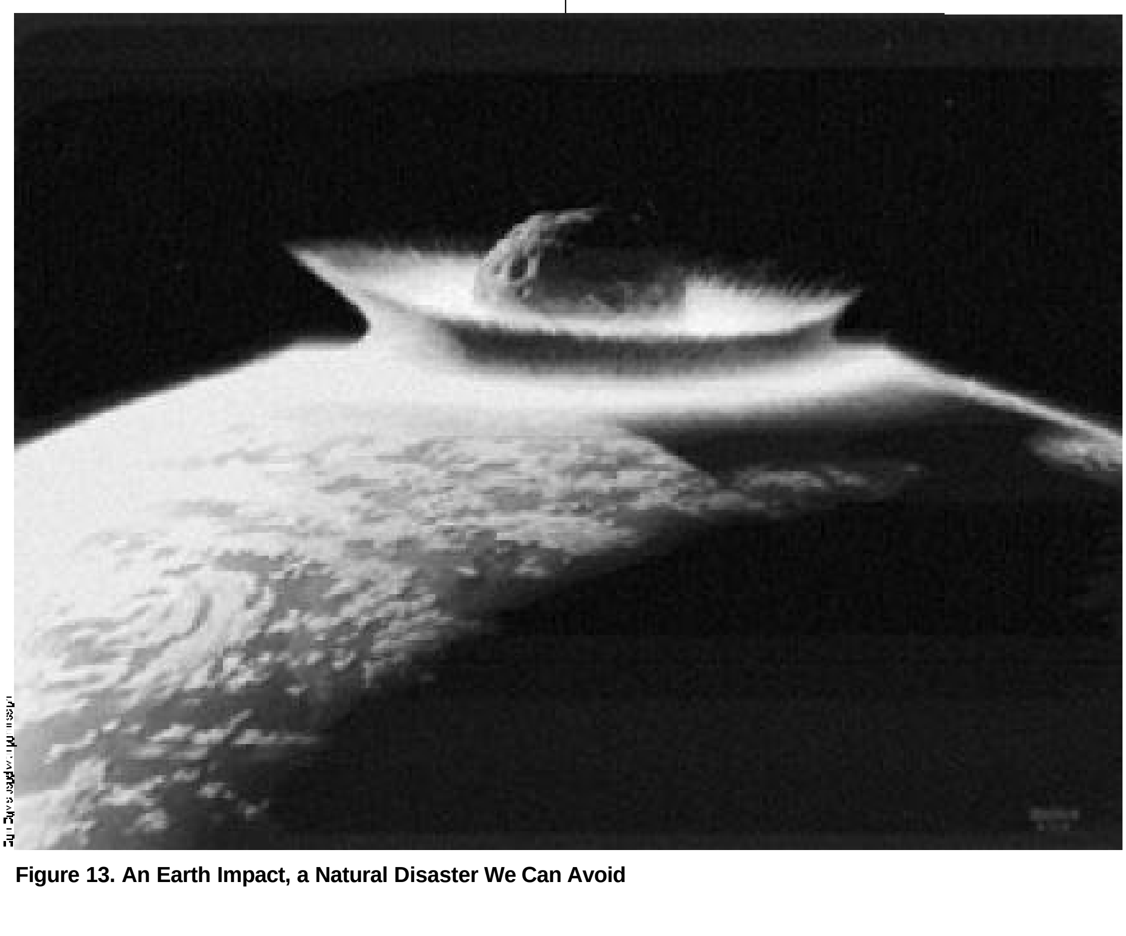

Figure 13. An Earth Impact, a Natural Disaster We Can Avoid

Notes

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27. National Aeronautics and Space Administration, "Report of the Near-Earth Objects Survey Working Group," presented to the Committee on Science, House of Representatives, June 1995, preface to the Honorable Robert Walker.
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31. Nick Fuhrman, professional staff member, Eric R. Sterner, professional staff member, Richard M. Obermann, science advisor, Committee on Science, Subcommittee on Space and Aeronautics, US House of Representatives, private communication with the authors, 12 September 1995.
32. Bell, Bender, and Carey, chapter 7.
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34. Maj Lindley N. Johnson, private communication with the authors, 15 December 1995.

Nothing in the world is more dangerous than sincere ignorance and conscientious stupidity.

—Martin Luther King Jr.